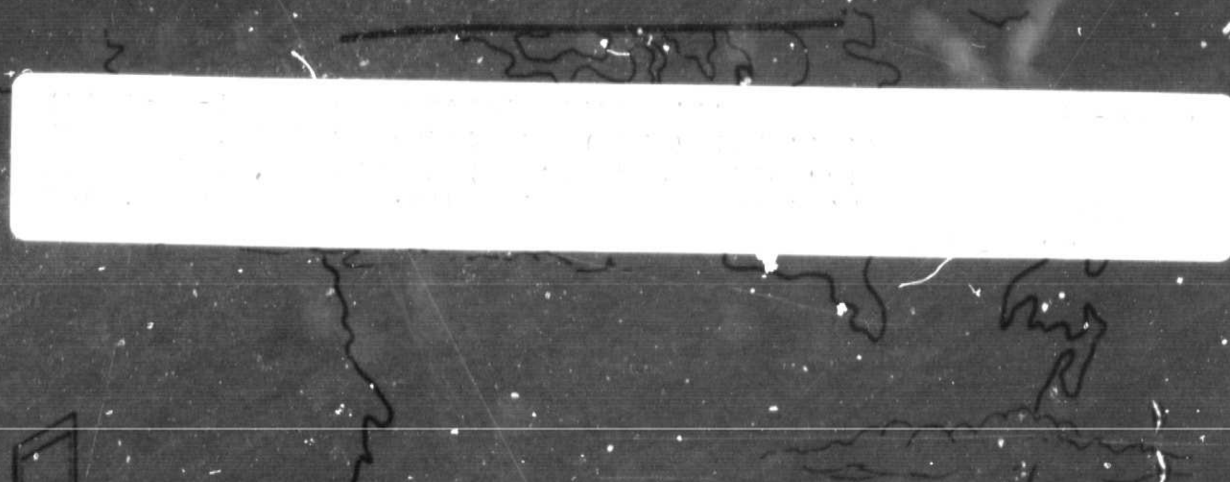
CTS COMMUNICATIONS LINK CHARACTERIZATION EXPERIMENT TECHNICAL DATA REPORT

VOLUME 2

APRIL 1977



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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Goddard Space Flight Center

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long term rain rate statistical analysis

COMMUNICATIONS LINK CHARACTERIZATION EXPERIMENT (CLCE)

Volume 2

TECHNICAL DATA REPORT

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APRIL 1977

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SECTION 1
INTRODUCTION

The purpose of this report is to present the results of the long term rain rate statistical analysis and the results of the investigation of determining the "worst" month statistics from the measured attenuation (δ) data caused by precipitation. The rain rate statistics cover a period of 11 months from July of 1974 to May of 1975 for measurements taken at the NASA, Rosman station. For the δ data, the total measurement period that was considered extends from June through October of 1976. This data was measured at the NASA, Goddard, CTS Station in the above period.

The rain rate statistical analysis is a continuation of the analysis of the rain rate data accumulated for the ATS-6 Millimeter Wave Propagation Experiment. The statistical characteristics of the rain rate data through December of 1974 is also presented in the final data analysis report[1] for the above experiment. Rain rate data for the January to May 1975 period were reduced in a period subsequent to the issuance of the above report.

SECTION 2
ATTENUATION STATISTICS

For this report the attenuation (δ) measurements taken at the Goddard CTS station for the period of June through October of 1976 will be considered for evaluating the "worst" month statistics. This limited sample should suffice since the periods of heaviest and prolonged precipitation for the year occurs in the June through October period tending to peak in the three month period of July, August, and September. Of these 3 months, it has been determined that the month of August has been the period of heaviest precipitation in the eastern section of the country in which North Carolina, Maryland, and Washington, D.C. are located.

At the Goddard station the received 11.7 GHz signal transmitted by the CTS satellite is recorded on a strip chart. Utilizing the received signal level obtained during a clear weather condition as a reference, the δ value is measured in a time increment of one minute. The elevation angle of the ground antenna is set at 29.5°. For a widespread uniform rain environment in which a melting layer exists, it can be shown that for the period of interest (June, July, and August) the height of this layer is approximately 3.5 km relative to sea level. For the above parameters it follows that the corresponding slant range through the precipitation region is 7 km. At the 11.7 GHz frequency, a rain rate of 20 mm/hr will produce a δ value of about 5 dB. For a rainy month such as August, the percentage of time that the rain rate exceeds 20 mm/hr can easily be higher than 0.1% of the month; thus causing problems for systems that have limited fade margins.

Various definitions can be developed for defining "worst" month statistics from data obtained from a number of months. It would involve choosing an arbitrary level of say 5 dB and then defining the "worst" month as the month in which the above δ level was exceeded for the maximum time percentage of the month. Another criteria would be to choose the month in which the highest δ value was measured. For communication systems with relatively low fade margins, the former criterion is more applicable. Of course, both criteria could be met in a particular month since they are not mutually exclusive.

The two months in which the highest and most prolonged values of δ were measured are July and August. The cumulative distributions for both months are shown in Figures 1 and 2, respectively. In comparing the statistics of the two months, August fulfills both requirements for the "worst" month criterion. The data for July and August were obtained from measurement periods of 14,933 minutes for July and 9130 minutes for August. These data acquisitions are the times in which a measurement of δ was attempted for various types of weather conditions that did not always include periods of precipitation. Since the cumulative distributions are normalized to the total time period of the month (44,640 minutes), the percentage values are not a function of the acquisition times.

The corresponding worst month statistics obtained to date from the Rosman station is shown in Figure 3. Four second mean values are employed for the cumulative distribution. For the Rosman station the month of July produced the highest δ values. In comparing the attenuation statistics for the Rosman and Greenbelt stations for the month of July, it is noticed that the time within the month that produced the measurable δ values was about 0.3% (129 minutes) for Rosman and 0.15% (67 minutes) for Greenbelt. The difference is probably due to the lower averaging time (4 seconds versus 1 minute) employed at the Rosman station. For the month of August, the magnitude of attenuation data measured at the Rosman station relative to the values obtained at the Greenbelt (Goddard) station was much lower (3 dB vs 20 dB). At the former station 210 minutes of δ data was recorded and the peak 4 second value was 3 dB. At the Greenbelt station, 268 minutes of data was measured, with a resulting peak minutely mean value greater than 20 dB. Since the measurement times are equivalent and both stations are located within the same geographical region a better correlation between peak δ values would be expected for long term statistics. Three possible reasons for the discrepancy are as follows:

a. Comparison of the statistics for a time period of one month is too short a period for the distances between stations.

b. The high δ values were mainly caused by localized storms in the Greenbelt area.

c. In August of 1976 the Rosman station was only recording δ data for an 8 hour time period each day whereas Greenbelt recorded data over a 24 hour time period.

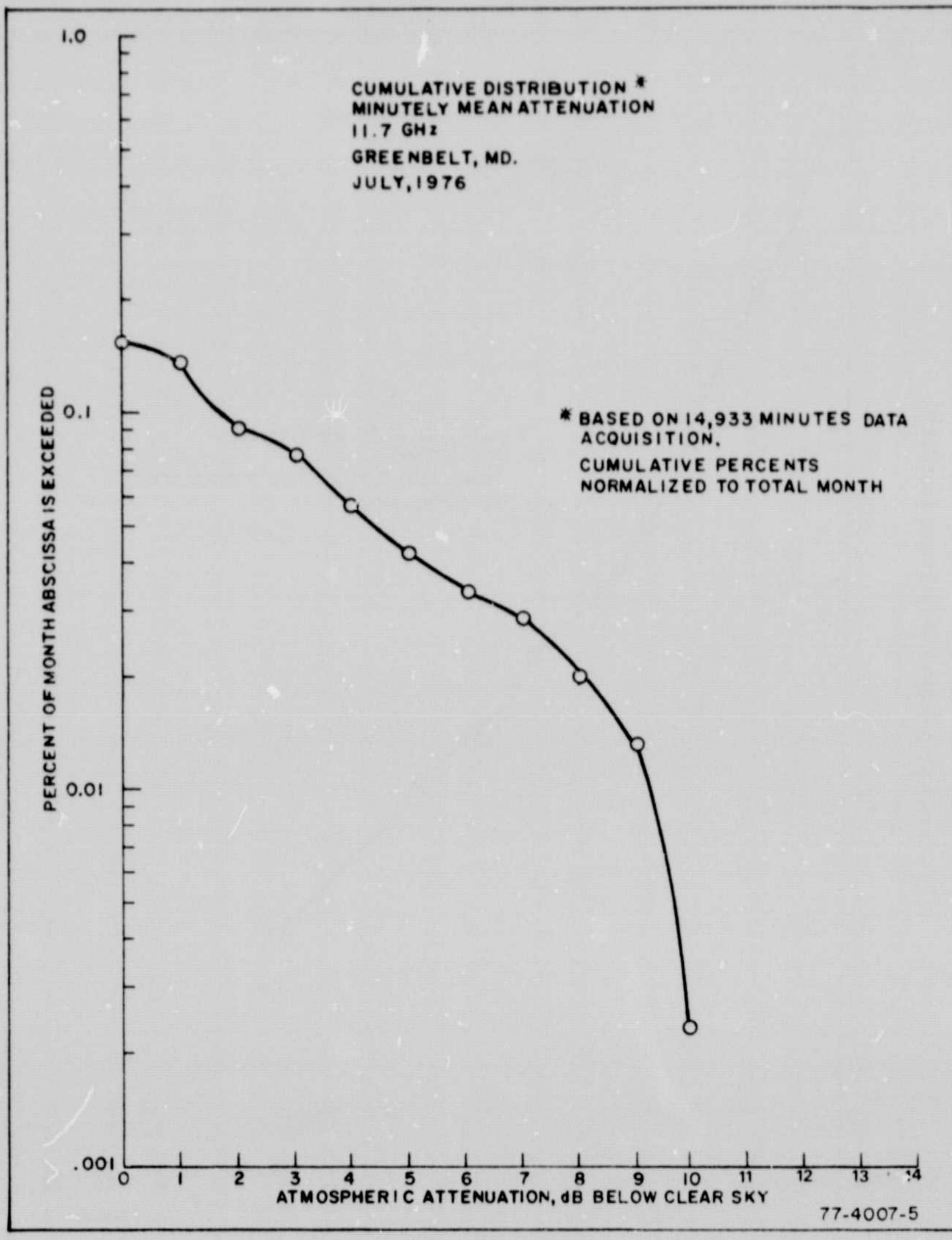

Figure 1. NASA Goddard CTS Station, Minutely Average Attenuation for July 1976

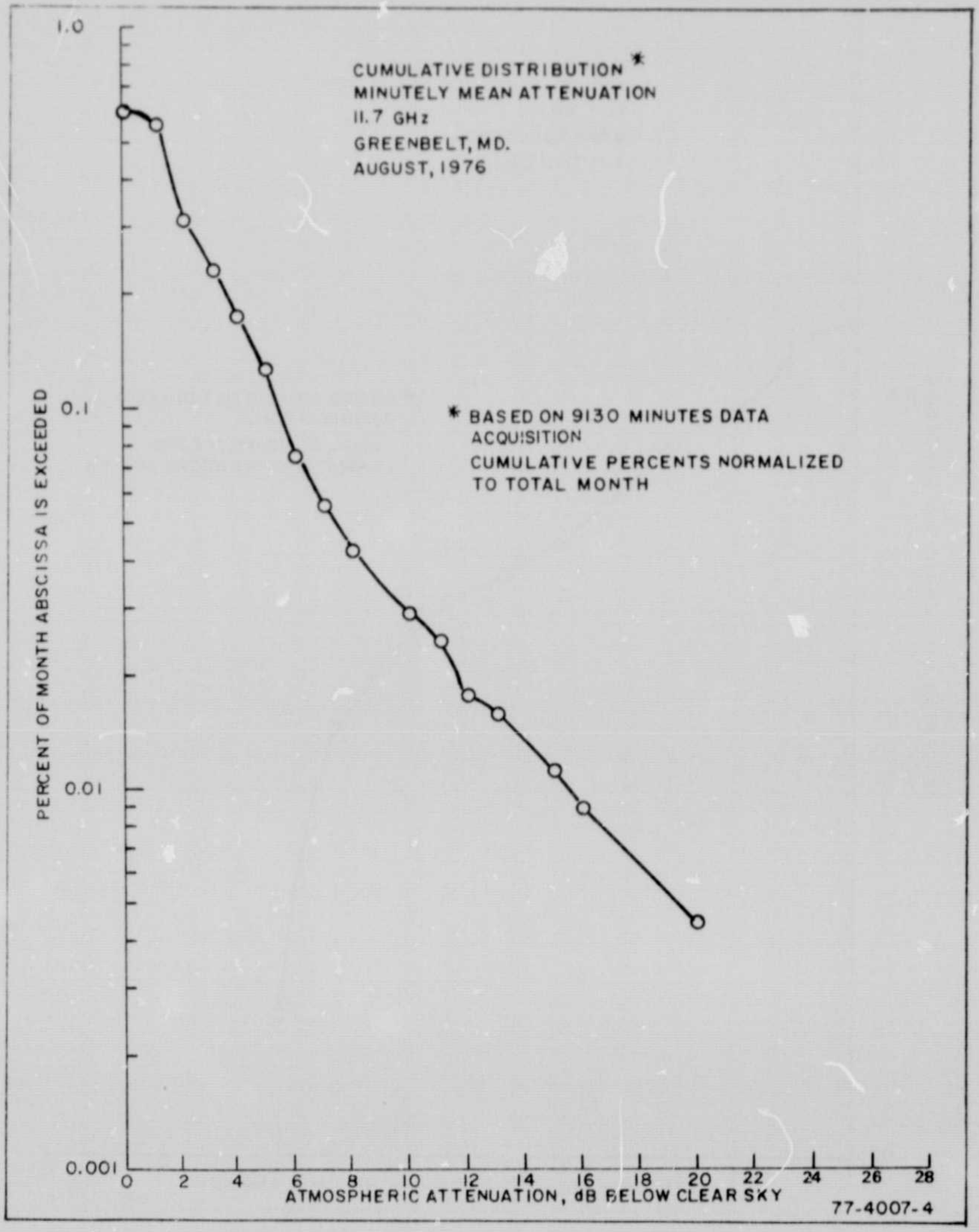

Figure 2. NASA Goddard CTS Station, Minutely Average Attenuation for August 1976

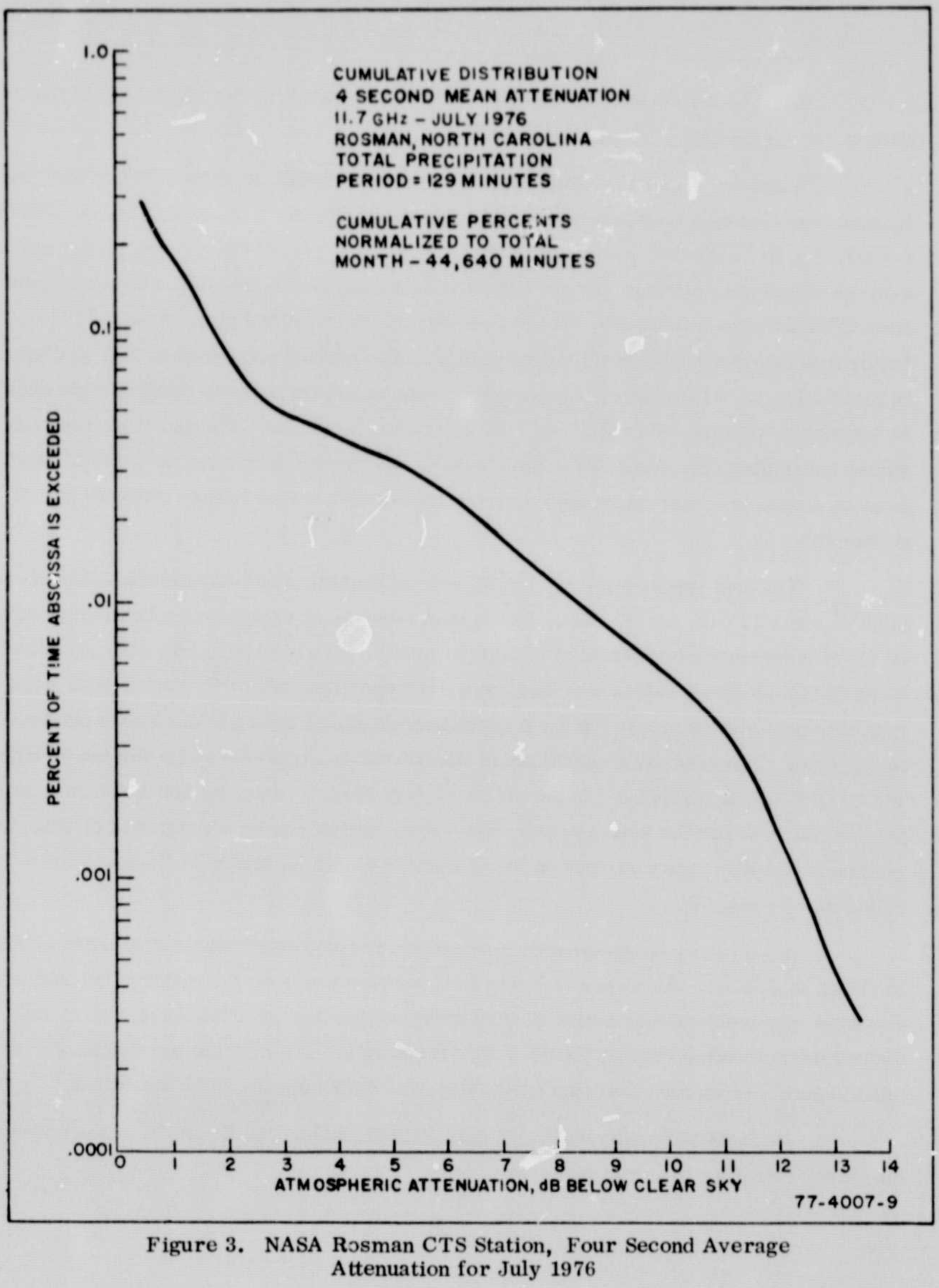

Figure 3. NASA Rosman CTS Station, Four Second Average Attenuation for July 1976

d. The differences in the averaging times result in the smoothing of the δ data at values generally greater than 10 dB.

Figure 4 shows the cumulative plots for the month of July 1976 for both the Rosman and Goddard stations. Reasonable correspondence in the statistics is obtained considering the different averaging times. In the 2 dB to 10 dB δ range higher percentage values was obtained for the Goddard data despite the fact that a lower sample time of 67 minutes versus 129 minutes existed for the Goddard plot. One possible factor that may help explain this discrepancy is the method employed at both stations in measuring δ. At Goddard, the measurements are taken directly from a strip chart at 1 minute intervals. For Rosman, the δ measurements are obtained from secondly values by employing a computer. As a result, the manual technique at Goddard should produce a coarse δ measurement requiring higher values of δ to note changes in this parameter.

The test frequencies for the ATS-6 Millimeter Wave Propagation Experiment[1] were 20 GHz and 30 GHz. Because of scheduling problems, a limited amount of δ measurements were obtained in a given month. In order to obtain representative monthly cumulative δ values a method was developed by Ippolito[2] that utilized δ and rain rate pair values measured for a given percentage of time for the δ data acquisition period. The prediction technique is illustrated in Figures 5 and 6 for the 30 GHz and 20 GHz test frequencies for the month of July 1974. Assuming the δ and rain rate pair values hold for the entire month, the δ distribution can be constructed by utilizing the measured rain rate distribution for the entire month as shown in Figure 5 for a rain rate of 9 mm/hr.

A summary of the monthly δ statistics for all distributions discussed above is shown in Table I. As shown in Table I, if service times on the order of 99.99% are a system requirement then required fade margins due to rain attenuation are an important consideration even at the 11.7 GHz frequency. If a service time of 99.9% is permissible then system margins on the order of 6 dB appears to be sufficient.

An empirical expression [3] that relates attenuation (δ) in dB to the ground measured rain rate (R), in mm/hr, is,

$$\delta\ (\mathrm{dB}) = a\, R^{b}\, L$$

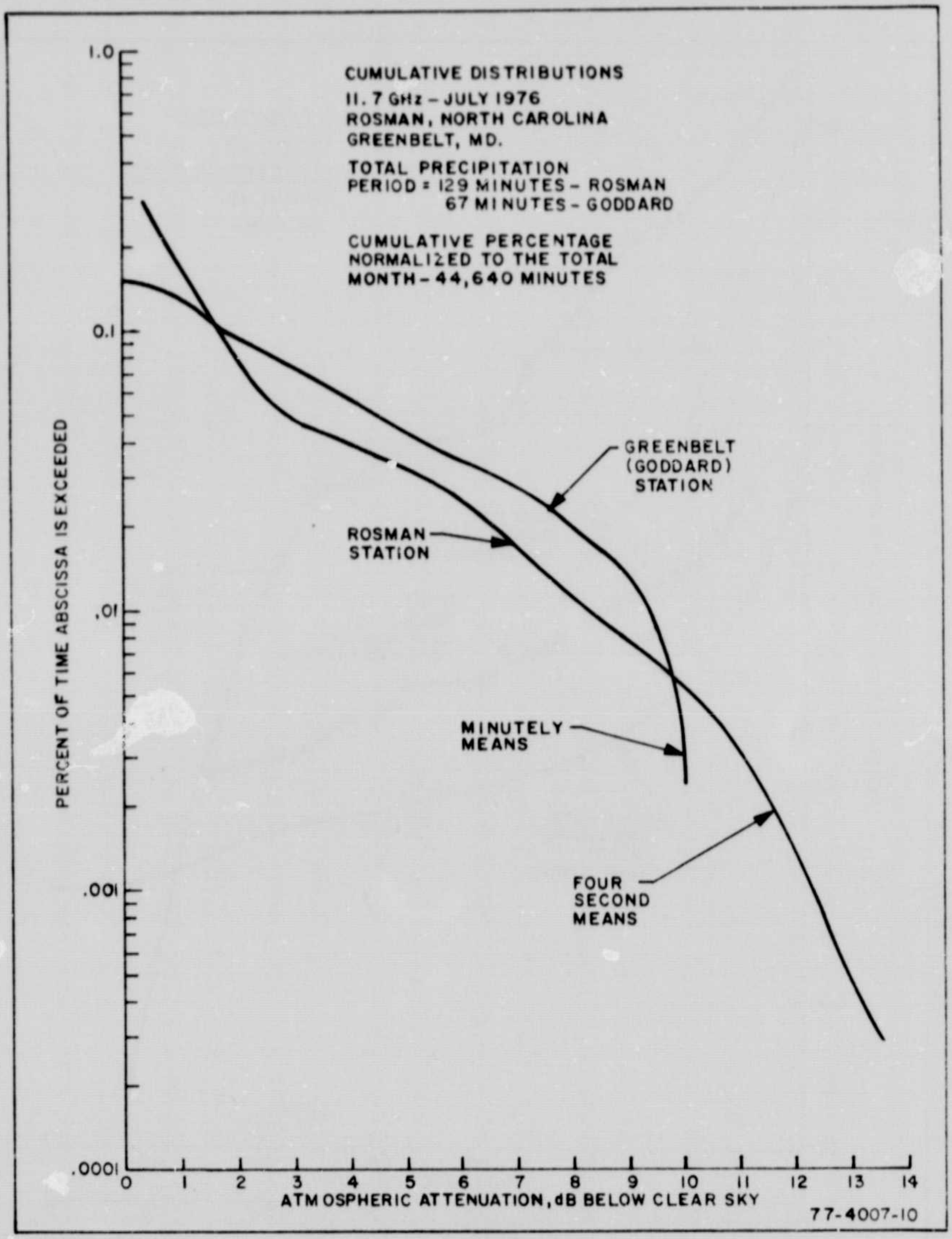

Figure 4. Cumulative Distributions for July of 1976 for Both NASA Rosman and Goddard Stations

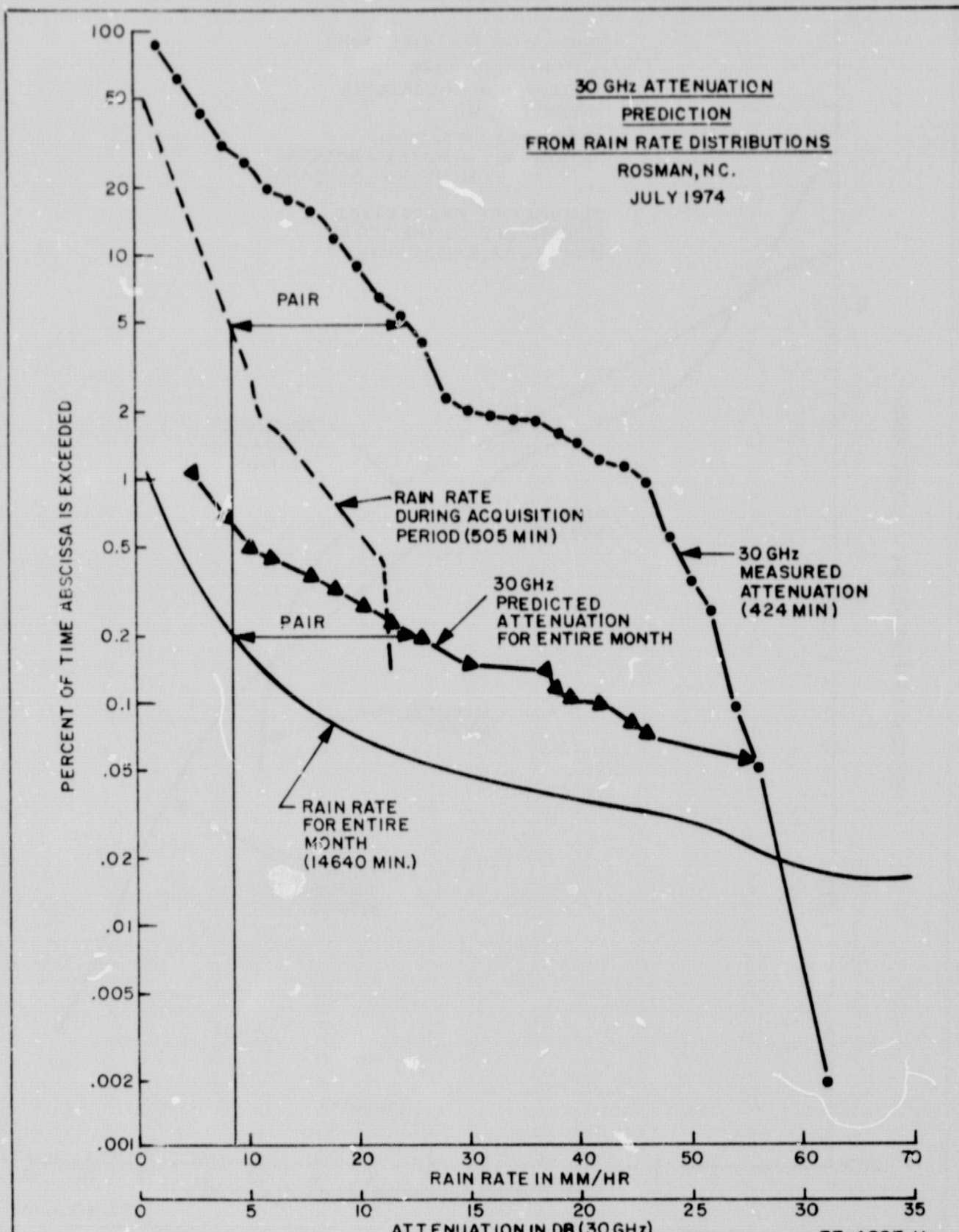

Figure 5. 30 GHz Attenuation Prediction From Rain Rate Distributions

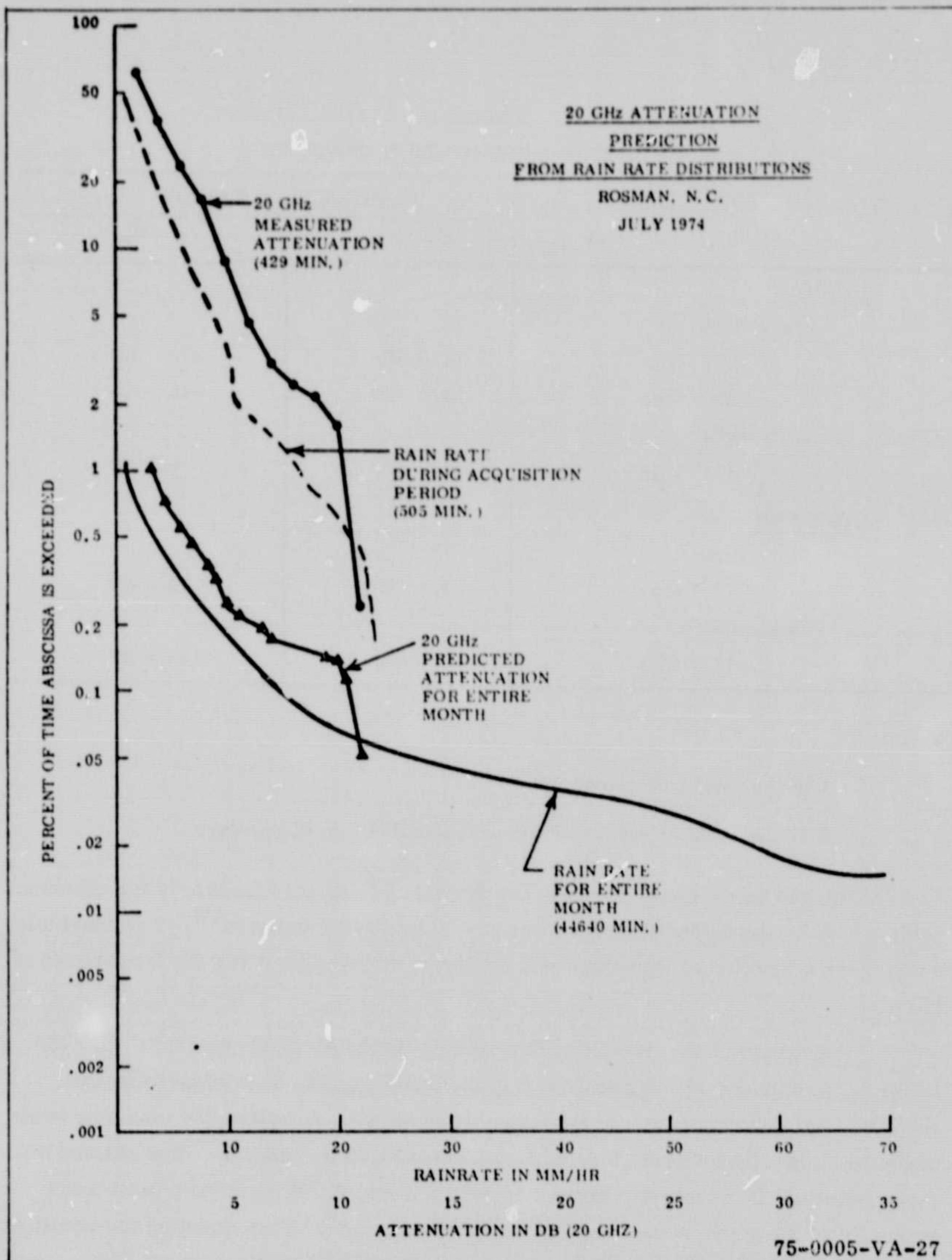

Figure 6. 20 GHz Attenuation Prediction From Rain Rate Distributions

TABLE I

SUMMARY OF ATTENUATION STATISTICS

	PERCENTAGE VALUES	
	0.1%	0.01%
<u>ROSMAN</u>		
July 1974		
20 GHz	11.0 dB	>20 dB
30 GHz	19.5 dB	>35 dB
July 1976		
11.7 GHz	1.7 dB	8.3 dB
<u>GODDARD</u>		
July 1976		
11.7 GHz	1.8 dB	9.4 dB
August 1976		
11.7 GHz	5.4 dB	15.6 dB

where

δ is the total path attenuation

R is the rainfall rate over the path length L, in kilometers.

The constraints in the above equation are developed from the Mie theory for spherical particles with a Laws and Parsons drop-size distribution assumed[(4)]. The constants a and b are a function of frequency and are listed in Appendix A for the frequencies of interest.

Because of the elevated path condition for an earth-to-spacecraft link the factor L is a function of the rain type, (geometrical aspects of rain environment), elevation angle and frequency of the transmitted signal. A method for obtaining some measure of the effective path length, L, was developed by Ippolito[(5)] that utilized the above equation and concurrent measurements of δ and R. It involved a least mean square fit of the above measurements to the function cR^d. Then equating the resulting function to the above equation,

$$cR^d = aR^b L$$

or

$$\frac{c}{a} R^{d-b} = L\ (R)$$

A plot of L (R) versus R for five different measurement conditions is shown in Figure 7. The particular parameters for each plot are listed in Table II.

From the above discussion it follows that L (R) should vary inversely with both frequency and elevation angle. For a given rain environment characterized by a height h and a large horizontal extent, the change in L with respect to a change in elevation angle θ is,

$$\frac{dL}{d\theta} = -h \frac{\cos\theta}{\sin^2\theta}$$

As θ varies from 45° to 30° the rate factor varies from -1.414 h to -3.46 h or L (R) increases by a factor of 0.9 h.

As the frequency increases, the "d" factor tends to approach unity as the frequency approaches 30 GHz thus causing the "d-b" factor to decrease. This causes the L (R) factor to become essentially independent of R for values of R > than ~20 MM/Hr as shown in Figure 7. Limiting values of L (R) for high R are listed in Table II for the 5 conditions. It appears that as the frequency and elevation angle increases the effective path length L becomes independent of R over a wide upper range of R values. Also for high δ values, the prediction of δ is more dependent on the R parameter and less on the L parameter.

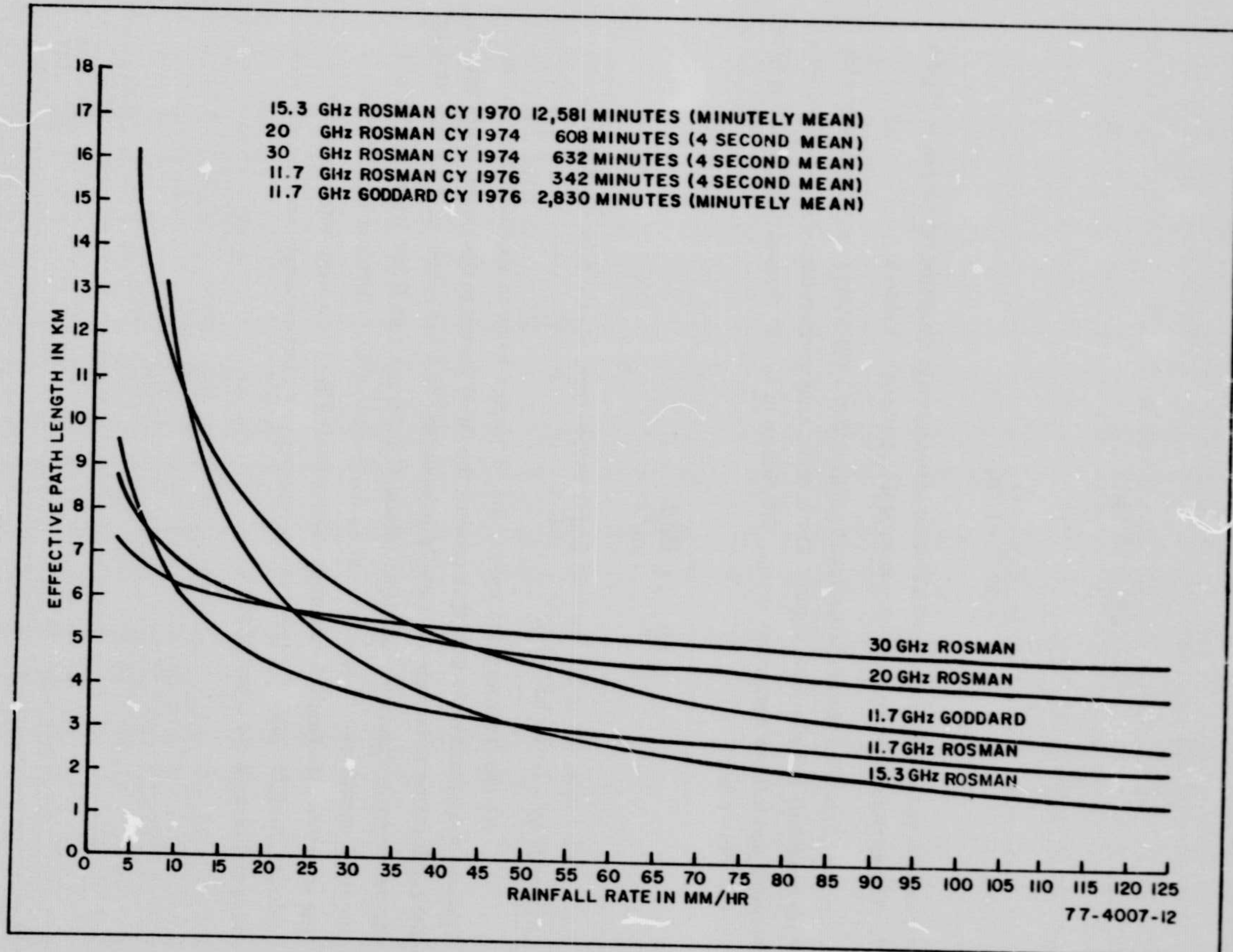

Figure 7. Effective Path Length Required for a Given Rainfall Rate

TABLE II

EFFECTIVE PATH LENGTH PARAMETERS

EXPERIMENT CONDITIONS	SATELLITE	NOMINAL ELEVATION ANGLE	cR^d	L(R)	LIMIT FOR L(R) IN Km
ROSMAN					
15.3 GHz	ATS-5	42°	$2.365\ R^{0.3663}$	$67.57\ R^{-.7887}$	1.5
20 GHz	ATS-6	45°	$.763\ R^{.885}$	$11.1\ R^{-.2154}$	3.9
30 GHz	ATS-6	45°	$1.389\ R^{.9154}$	$8.423R^{-.1199}$	4.7
11.7 GHz	CTS	36°	$.2476R^{.8583}$	$14.74\ R^{-.3917}$	2.2
GODDARD					
11.7 GHz	CTS	30°	$.661\ R^{.699}$	$39.345R^{-.557}$	2.7

SECTION 3

RAIN RATE STATISTICS

For all propagation experiments conducted at the NASA, Rosman station that relate to the effects of rain, the measurements of rain rate have been obtained from 10 tipping buckets placed approximately under the elevated radio beam. The distances from the 15-foot CTS antenna and the various rain buckets are shown in Table III.

TABLE III

RAIN BUCKET LOCATIONS

RAIN BUCKET NUMBER	DISTANCE IN METERS FROM CTS ANTENNA
1 (Near Bucket)	~0
2	280
3	494
4	640
5	907
6	1174
7	1481
8	1734
9	2027
10	2424

Tipping rain buckets are employed for determining the rain rate. The average rain rate was calculated from the time interval between bucket tips. The time of a bucket tip was recorded on a digital tape, accurate to the nearest second. The computation that converts time between tips to average rain rate between tips in mm/hr is

$$RR = \frac{914.4}{\Delta T}$$

where: 0.254 mm of rain over the gauge aperature per tip is assumed

ΔT is the time between tips in seconds

One second values of the rain rate are computed for the time period in which bucket tips were recorded. From these values, four second means and minutely mean values were computed. A required condition for a data sample for each of the defined time intervals was that a secondly value of rain rate exists for each second of the interval. If a data interrupt occurs for any reason, that particular time interval will be disregarded.

In order to characterize the precipitation region, a point rain rate and a ground average (GA) value was computed. The point rain rate was computed from the data from the bucket nearest to the ground antenna. This location is the nearest bucket to the elevated beam. It is defined as the near bucket (NB) value. In order to characterize the general precipitation area in which the elevated beam is located, an average value of the ten tipping buckets was computed. The degree of homogeneity in the precipitation region can be estimated by comparing the NB values with the GA values.

The time period for which the rain rate data has been reduced extends from July of 1974 to May of 1975. Rain rate statistics for this period are presented in the form of cumulative distributions which were computed on the basis of rain rate bins one mm/hr in width. To show how the rain rate characteristics vary between different time periods, distributions were computed for various quarterly periods as shown in Figures 8 and 9. All distributions were computed on the basis of the total time period covered by the distribution. For the total period considered, the July-August and September interval produced the largest amount of precipitation. This is not suprising since the summer months always produce a higher amount of precipitation. In figure 9 it is noted that a larger amount of precipitation was measured in the January through March period. This is due to the fact that in February of 1975 an abnormally high amount of precipitation was measured.

The cumulative distributions for the ground average (GA) rain rate values are shown in Figures 10 and 11. The reduced percentage values at the high rain rate values due to the smoothing effect of the averaging process is evident. Equivalent values (to the near bucket statistics) at rain rates lower than about 20 mm/hr show the homogeneous nature of rain at the lower values of rain rate.

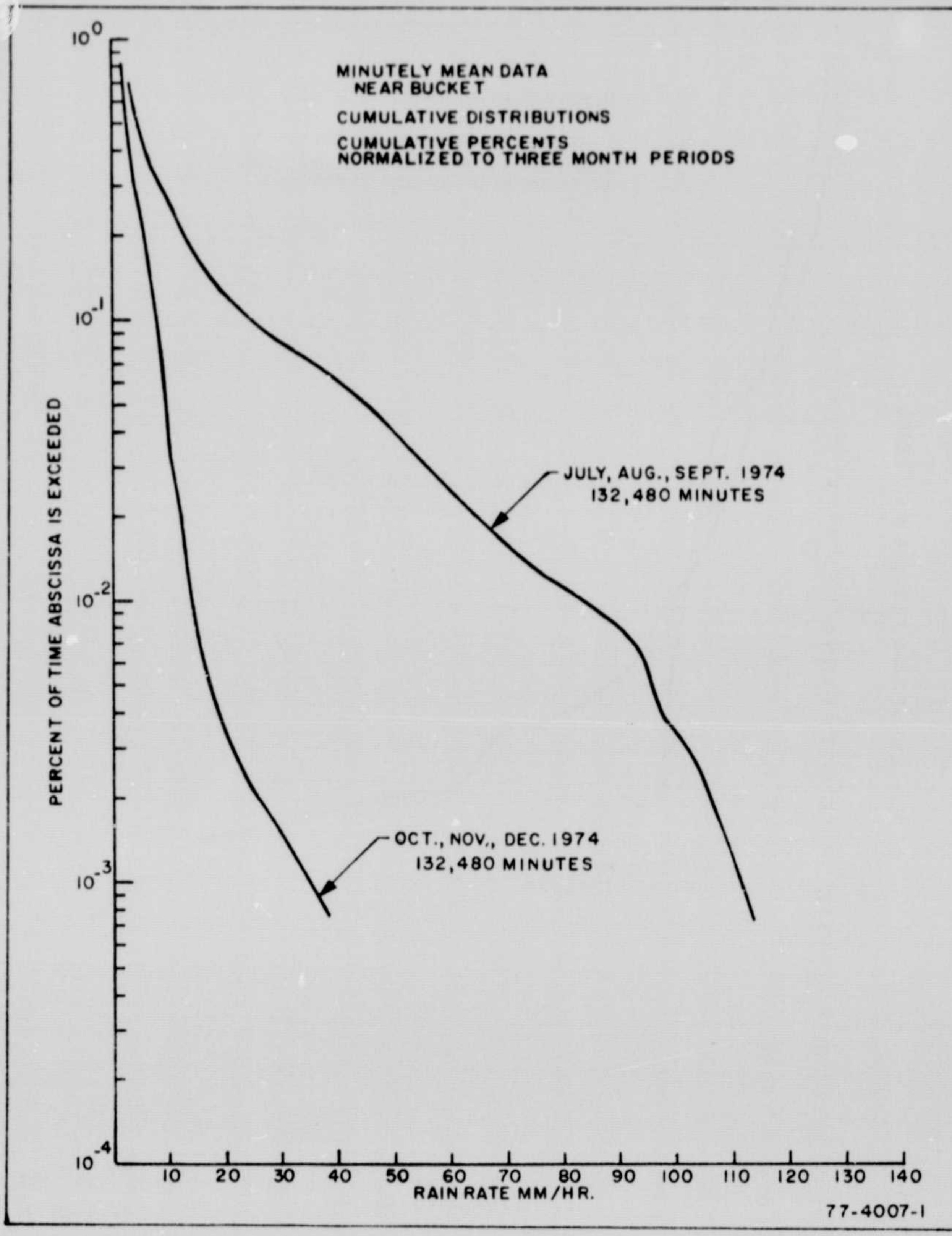

Figure 8. Minutely Mean Rain Rate Data (Near Bucket) for NASA Rosman Station, July to December 1974

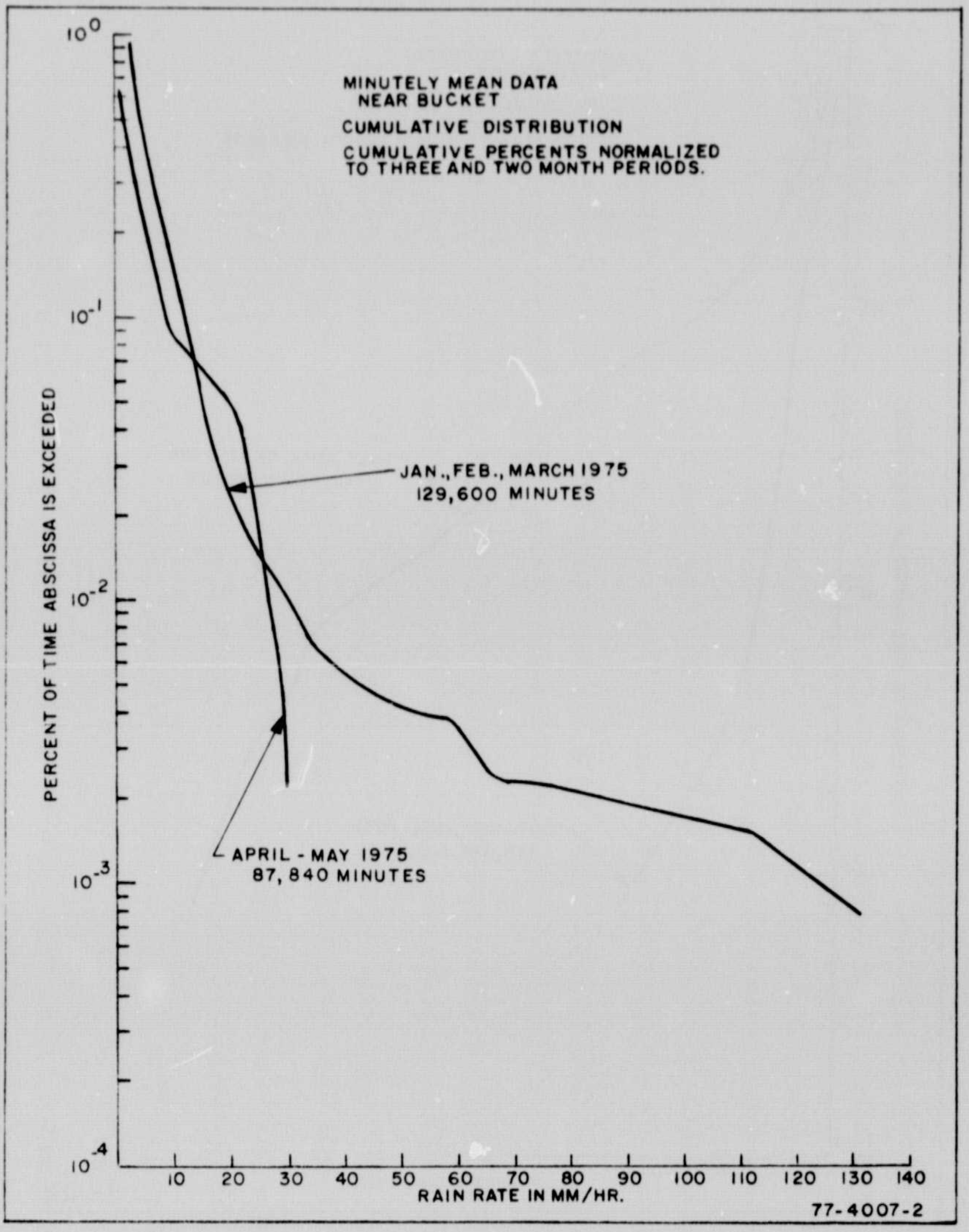

Figure 9. Minutely Mean Rain Rate Data (Near Bucket) for NASA Rosman Station, January to May 1975

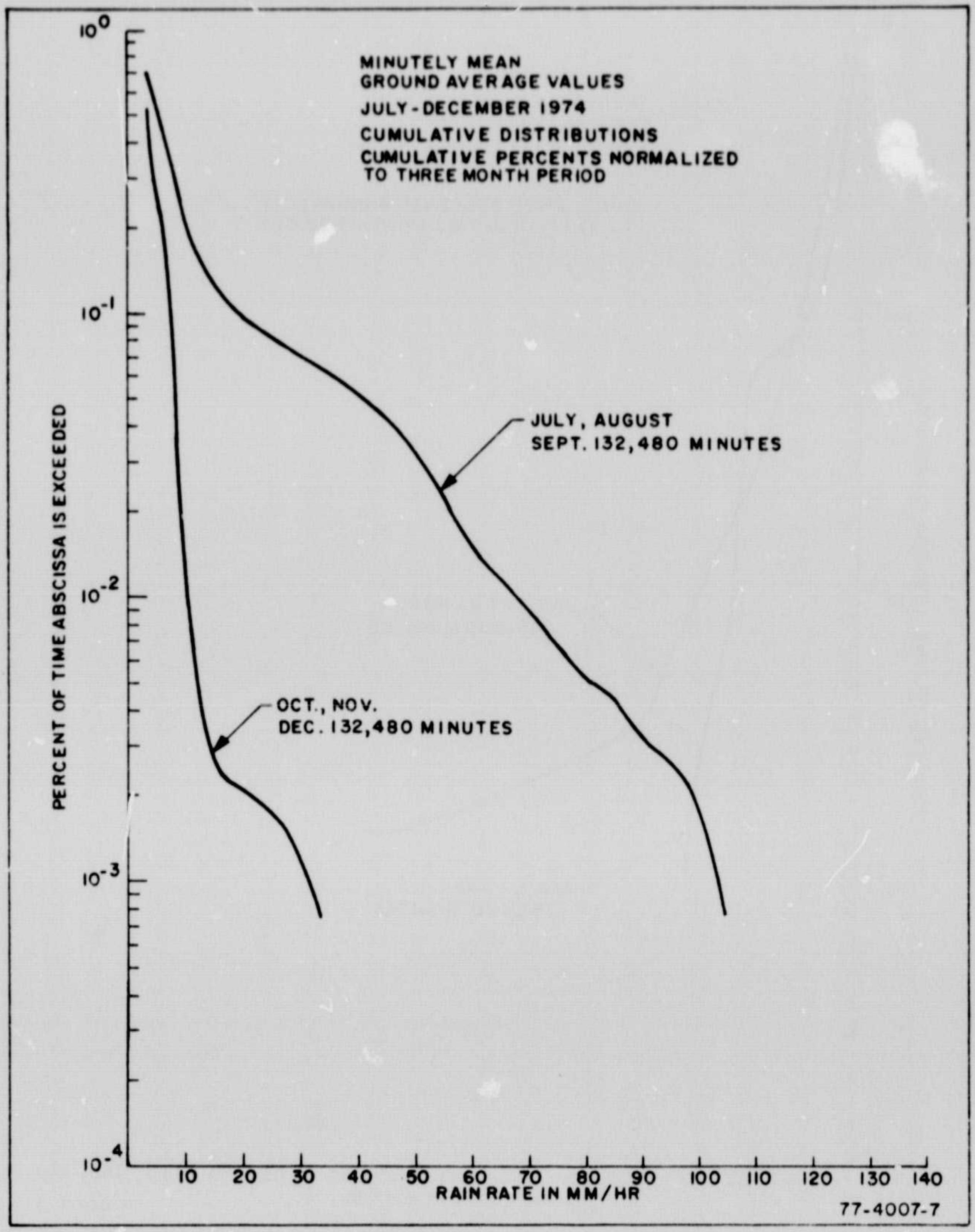

Figure 10. Minutely Mean Rain Rate Data (Ground Average) for NASA Rosman Station, July to December 1974

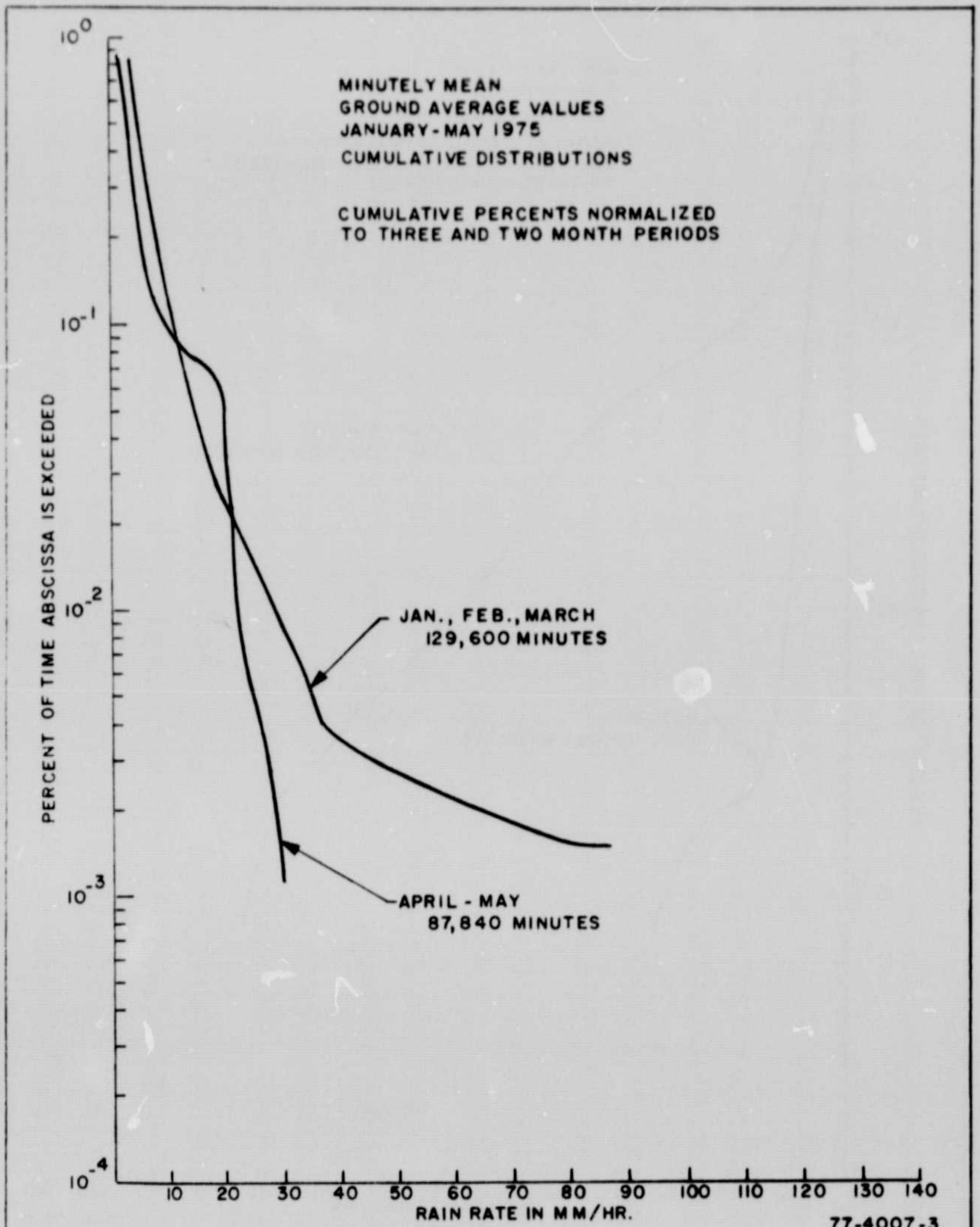

Figure 11. Minutely Mean Rain Rate Data (Ground Average) for NASA Rosman Station, January to May 1975

Cumulative distributions for the total measurement period for both NB and GA parameters are shown in Figure 12. For the long term plots, the NB statistics are a good measure of the GA statistics at rain rate values lower than about 50 mm/hr. Past this value the percentage values tend to diverage; however, the degree of divergence is gradual and the percentage values tend to track at high rain rate values.

The "worst" month statistics for the three computed parameters are shown in Figure 13. The pronounced divergence at the high values of rain rate show that the duration for intense rain rates have magnitudes that are on the order of seconds. This implies that deep fades will also only last for a correspondingly short period of time. A comparison of the rain rate statistics for the data presented in this report is shown in Table IV.

From the listed values in Table IV, it can be seen that the July through September period produced the greatest amount of precipitation with August being the month with the highest monthly precipitation. The October, November, and December period produced the least amount of precipitation. At the 0.1% factor, the October through May period produced essentially the same level of precipitation. At the 0.01% factor, the divergence between periods increased and was highest in the January through March interval due to an exceptionally heavy precipitation period in February. For the overall July through May period, the GA statistics tend to approach the NB statistics at a faster rate than the shorter time periods considered. For yearly statistics, it appears that the NB factor adequately describes the rain environment relative to the GA factor. For worst month statistics (August), four second mean valves are required to obtain rain rate information that relates to very deep fades caused by the rain.

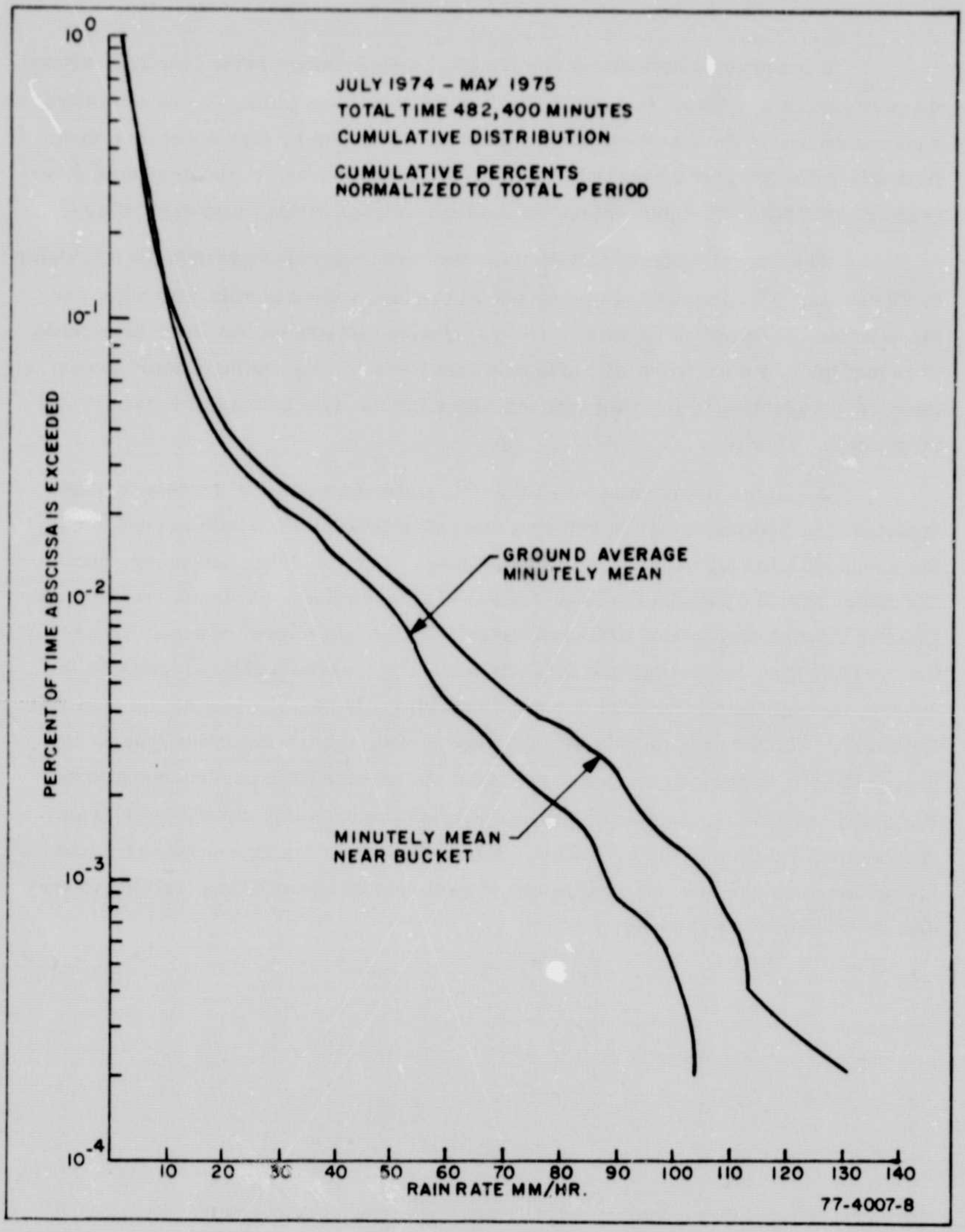

Figure 12. Long Term Minutely Mean Rain Rate Data for NASA Rosman Station, July 1974 to May 1975

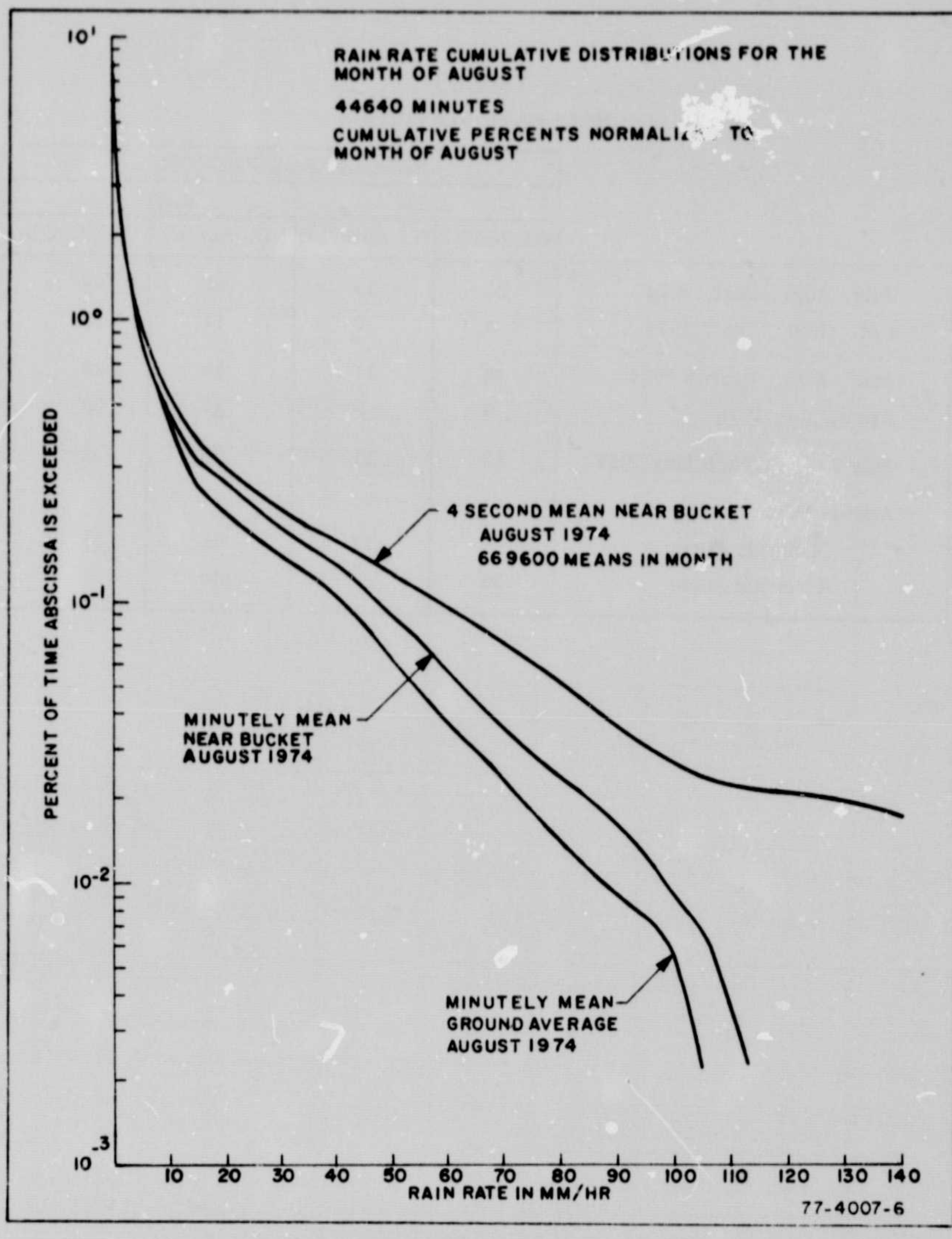

Figure 13. Rain Rate Cumulative Distributions for the Month of August 1974, NASA Rosman Station

TABLE IV

RAIN RATE STATISTICS

	PERCENTAGE FACTOR			
	0.1%		0.01%	
	NB (mm/hr)	GA (mm/hr)	NB (mm/hr)	GA (mm/hr)
July, Aug., Sept. 1974	25	19	83	68
Oct., Nov., Dec. 1974	8	7	14	10
Jan., Feb., March 1975	12	11	30	29
April, May 1975	9	9	27	23
July 1974 through May 1975	12	11	55	49
August 1974				
Minutely Mean	47	41	99	88
4 Second Mean	58		>140	

SECTION 4
SUMMARY

Attenuation and rain rate statistics for different stations and times are presented in this report. The attenuation data was obtained at the NASA, Goddard station over a time period of June through October of 1976. For comparison purposes, 20 GHz and 30 GHz attenuation data are also presented. The rain rate data was measured at the NASA, Rosman station over a period of July 1974 through May 1975.

From the standpoints of the time duration and magnitude of fade depth the "worst" month values occurred in the month of August. At the 0.1% and 0.01% percentage levels the corresponding attenuation values were 5.4 dB and 15.6 dB for the 11.7 GHz test frequency. For monthly statistics (not necessarily the worst month) at the 20 GHz and 30 GHz test frequencies the fade values at the 0.1% level was 11 dB and 19.5 dB, respectively. For the 0.01% level the fade levels were both greather than 20 dB. For the Rosman station, July of 1976 was determined to be the worst month. In this case the fade values for the 0.1% and 0.01% levels are 1.7 dB and 8.3 dB, respectively. If service times on the order of 99.99% are a system requirement, then fade margins due to rain attenuation are an important consideration even at the 11.7 Ghz frequency.

A measure of the effective path length L (R) for an elevated path through regions of precipitation was obtained for 5 data samples. The dependence of L on R tends to decrease as the antenna elevation angle and frequency increases. Also for high δ values, the prediction of δ is more dependent on the magnitude of the rain rate (R) and less on the L parameter.

For the rain rate (essentially minutely mean values) measurement period of July 1974 through May of 1975, the July, August, and September period produced the largest amount of precipitation with August being the month with the highest monthly precipitation. The October, November, and December period produced the least amount of precipitation. For the overall July through May period the Ground Average

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statistics tend to approach the Near Bucket statistics at a faster rate than any other time periods considered. For the month of August, at percentage values of 0.1% and 0.01%, the near bucket rain rate values are 47 and 99 mm/hr, respectively. For rain rates that produce very deep fades, 4 second mean values are required to determine the necessary rain rate information that relates to these deep fade levels. For yearly statistics; it appears that the Near Bucket values adequately describes the rain environment relative to the Ground Average values.

REFERENCES

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(2) Ippolito, L.J., "ATS-6 Millimeter Wave Propagation and Communications Experiments at 20 and 30 GHz;" IEEE Transactions on Aerospace and Electronics Systems, Vol. AES11 No. 6, November 1975

(3) Gunn, L.S. and East, T.W.R., "The Microwave Properties of Precipitation Particles, Journal of the Royal Meteorological Society, Vol. 80, 1954

(4) Laws, J.O. and Parsons, T.A., "The Relation of Raindrop Size to Intensity," Transactions, American Geophysical Union, Hydrology, 1943

(5) Ippolito, L.J., "Summary and Evaluation of Results from the ATS Millimeter Wave Experiment," May 1972, NASAX-751-72-208, Goddard Space Flight Center, Greenbelt, Maryland

APPENDIX A

Power Curve Best Fit Coefficients For Medhurst Calculated Attenuation Factors (Laws & Parsons Drop Size Distribution)

Consider Table V of Medhurst (1965). Assume

$$A\ (\mathrm{dB/km}) = a\ R^b,\quad R \text{ in } \frac{\mathrm{mm}}{\mathrm{hr}}$$

Then, using power curve regression fit (HP65, STAT 1-24A), the a & b coefficients are found. r^2, the coefficient of determination, is also listed.

Freq (GHz)	λ (cm)	a	b	r^2
2	15			
3	10			
3.33	9			
3.75	8			
4.29	7			
4.62	6.5			
5	6			
5.45	5.5	0.0012	1.2294	
6	5	0.0018	1.2485	0.9945
7.5	4	0.0035	1.3020	0.9975
10	3	0.0094	1.2791	0.9997
15	2	0.0328	1.1710	0.9988
20	1.5	0.0687	1.1004	0.9993
30	1	0.1649	1.0353	0.9989
60	.5	0.6050	0.8554	0.9981
100	.3	0.9395	0.7886	0.9954
11	2.73	0.0159	1.25	
12	2.5	0.0168	1.25	
14	2.14	0.0265	1.19	
15.3	1.96	0.035	1.15	
31.65	0.95	0.0185	1.00	